Alternative Penetrometers to Measure the Near Surface Strength of Soft Seafloor Soils

Mark R. Tufenkjian
Department of Civil Engineering, California State University, Los Angeles
5151 State University Drive
Los Angeles, California, 90032
phone:(323) 343-4434 fax:(323) 343-6316 email:mtufenk@calstatela.edu

Award Number: N00014-08-1-0353 and N00014-10-1-0427

LONG-TERM GOALS

Develop an alternative penetrometer to accurately measure the undrained shear strength of near surface soft seafloor soils. Further the education of participating undergraduate and graduate students by active involvement in research and mentoring activities.

OBJECTIVES

In collaboration with the Naval Facilities Engineering Service Center (NFESC) in Port Hueneme, assess the feasibility of using full-flow penetrometer technology to meet Navy requirements. Design, build, and test a full-flow penetrometer that will accurately measure the near surface shear strength of soft seafloor soils.

APPROACH

Review current full-flow penetrometer technology:
Review technical literature to evaluate the state-of-the-art in full-flow penetrometer technology. Discuss with end users and manufacturers the state-of-practice of full-flow penetrometers in scientific and engineering practice. Identify unresolved issues of flow-penetrometer technology and how they can be met to meet the needs of the Navy.

Probe design and construction:
Select probe type and size for design and construction. The probe will be designed to be compatible with the Navy's seabed cone penetrometer unit. The probe will be outfitted with load cells to measure penetration resistance, sleeve friction, and a pressure transducer to measure porewater pressures. Nearly all full-flow penetrometers in use today are either spherical (ball) or cylindrical (t-bar). The features and characteristics most critical to the needs of the Navy will dictate the selection of the probe type.

Laboratory Probe Calibration:
Calibration will be performed in the laboratory by pushing the full-flow penetrometer into prepared large-scale Kaolin specimens of known strength and comparing the measured resistance with the specimen's undrained shear strength. The ratio of these quantities is the experimentally determined

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2012**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Alternative Penetrometers to Measure the Near Surface Strength of Soft Seafloor Soils**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Civil Engineering, California State University, Los Angeles 5151 State University Drive Los Angeles, California, 90032**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**		
13. SUPPLEMENTARY NOTES **The original document contains color images.**		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

laboratory probe factor. Adjacent cone penetrometer and vane shear tests will also be performed in the specimens to allow side-by-side comparisons and evaluation of the penetration resistance and shear strength with depth; and to establish a baseline to assess the improvement in shear strength accuracy for the full-flow penetrometer. Also, undisturbed samples will be taken from the Kaolin specimens and tested by consolidated undrained triaxial compression/extension tests and by direct simple shear tests.

Probe Validation through Field Trials:
Field testing at onshore sites will be conducted to validate the recommended probe factors against real soils. The probe factors from the field trials will be calculated and compared with the theoretical and laboratory determined values. Ultimately, the potential of the full-flow penetrometer to more accurately determine the shear strength of soft soils (compared to the CPT and Vane Shear) will be evaluated. Parallel CPTs and vane shear tests will also be performed to allow side-by-side comparison and evaluation of the penetration resistance and shear strength with depth; and to establish a baseline to assess the improvement in shear strength accuracy for the full-flow penetrometer. High quality undisturbed clay samples will be obtained for laboratory strength testing (triaxial and simple shear).

Educational Program:
One of the main objectives of this project is to actively involve undergraduate and graduate students in the research effort and to provide mentorship. The project involves three undergraduate and three graduate civil engineering students in research and mentoring activities throughout the duration of the project.

WORK COMPLETED

The *Laboratory Probe Calibration* testing in the Kaolin specimens is complete. A total of five full-scale Kaolin specimens (Specimens 1 through 5) have been prepared and tested. Each specimen had final consolidated dimensions of approximately 1.1 m in diameter by 1.3 m in height. Each was prepared by mixing 2,700 pounds of Kaolin powder with 450 gallons of water and applying a consolidation pressure and allowing the water to drain at the top and bottom boundaries. Consolidating the specimens took about one to two months each to complete depending upon the applied pressure. Turnaround time for each specimen was about 4 months. The equipment and procedures developed to prepare uniform and homogenous large-scale clay specimens has been a key accomplishment for this project.

The readied specimens were tested by advancing a standard ball penetrometer (100 cm^2), mini-ball penetrometer (20 cm^2), cone penetrometer (10 cm^2), and vane shear device. A photograph of the probes is shown on Figure 1. The results were used to evaluate and compare the undrained shear strengths derived from each device. Core samples were retrieved for subsequent triaxial and direct simple shear testing. Digital imaging was used to observe the flow mechanism during shallow penetration.

The *Probe Validation through Field Trials* phase is nearly complete. The first field site was tested at a rock quarry site in Irwindale. Soft and fine grained tailings were tested in an old spreading pond at the site. A total of six spherical ball and cone penetrometer tests were performed over a two day period. Core samples were also retrieved. A second site for another round of testing is currently being located.

The *Education Program* component is ongoing and progressing well. Two undergraduate civil engineering students completed their work on the project in December. One of the students graduated

with her B.S. degree in Civil Engineering and the other is on track to graduate this year. Both have expressed interest in pursuing their M.S. degree in Civil Engineering. Three graduate civil engineering students are also working on the project. One of the students completed his Master's thesis by analyzing more than two dozen direct simple shear tests he conducted on core samples retrieved from Specimens 1 through 3. He has since graduated and, aside from his full-time professional job, teaches the undergraduate soils mechanics laboratory course utilizing his experience with lab equipment gained from the project. The other graduate student has just completed the triaxial strength testing program and is now preparing his thesis. A photograph of him is shown on Figure 2. The third graduate student is currently conducting additional direct simple shear tests on samples retrieved from Specimens 4 and 5. He will use this information to complete his thesis.

RESULTS

As mentioned earlier, five tests (Specimens 1 through 5) have been completed. Each test represents a different clay consistency. For each test, four different types of probes were advanced side-by-side in order to allow a comparison of the recorded data. The average net tip resistance profile for the BPT for Specimens 1 through 5 are shown on Figure 3. The shape and magnitudes of the tip resistance profiles are consistent and in line with other soft clay tests reported in the literature. As expected, the magnitudes of tip resistance increase as the soil becomes stiffer for each probe type.

The undrained shear strengths computed using all of the probes are currently being evaluated against the benchmark strengths from the triaxial and direct simple shear tests. The triaxial and direct simple shear testing is nearing completion. New to the work this year is the testing of core samples to failure not only in triaxial compression but in extension as well as shown on Figures 4 and 5. Determining strengths in compression and extension provides a more accurate baseline from which the probe results can be evaluated. Having the equipment to test specimens in these complex modes of failure is significant to our research lab capabilities.

Test results conducted at the quarry site in Irwindale are being evaluated. Resistance and strengths will be analyzed and presented in the near future. A second site is currently being located such that a larger database of information can be collected and compared against the laboratory experiments.

IMPACT/APPLICATIONS

The impact of the research is to increase the technical capabilities of the Navy by developing a tool to measure the strength of soft seafloor soils. Results of this research will provide immediate and practical information for use by Navy commands. The project will also further the education of undergraduate and graduate students by active involvement in research and mentoring activities. It will expose the students to research projects important to the mission of the Navy with the intent that they may consider naval careers

RELATED PROJECTS

None

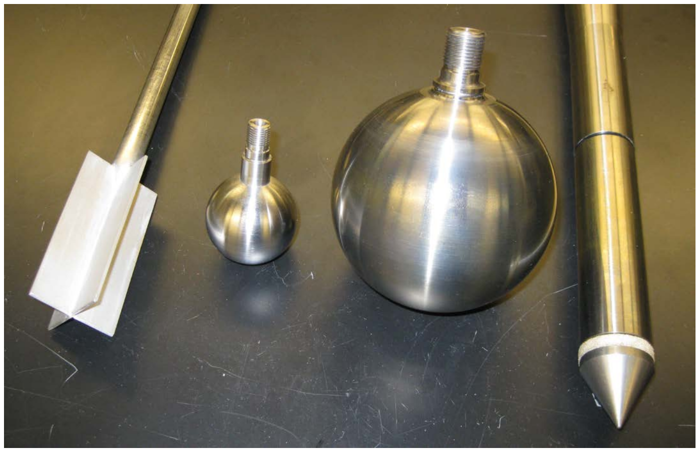

Figure 1: Photograph of probe types used in study. From left to right: vane shear, mini-ball, standard ball, and cone penetrometer.

Figure 2: Photograph of graduate student conducting triaxial strength testing on clay specimens.

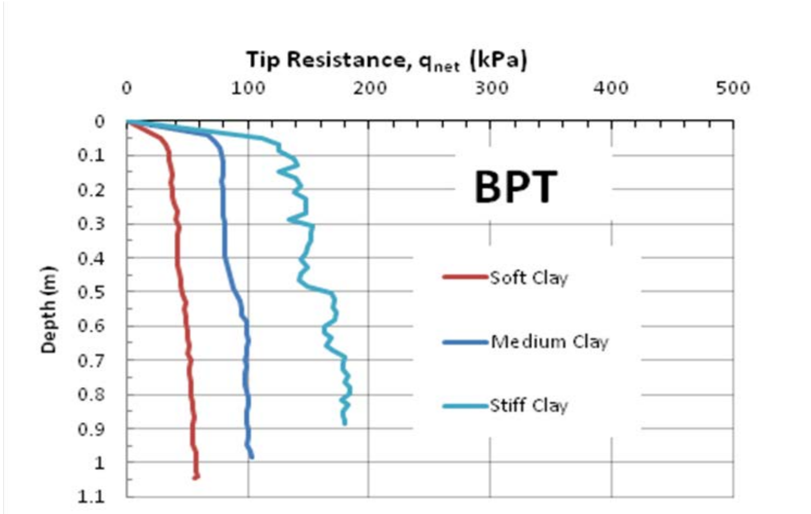

Figure 3: Graph showing profile of tip resistance with depth for the ball (BPT) penetrometer in soft, medium, and stiff clay.

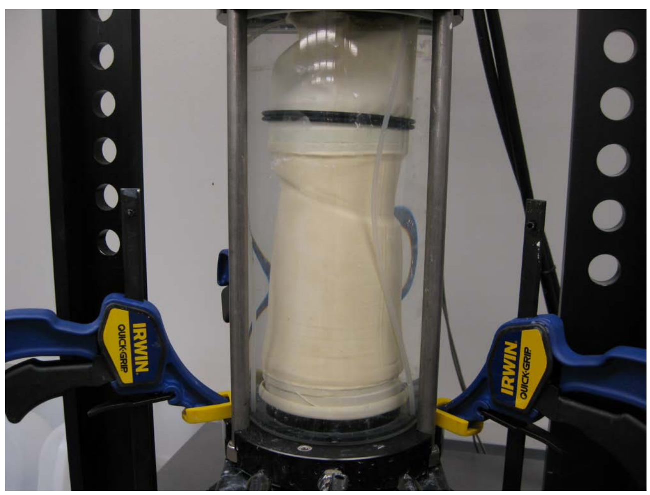

Figure 4: Photograph of clay specimen in triaxial device failing in extension.

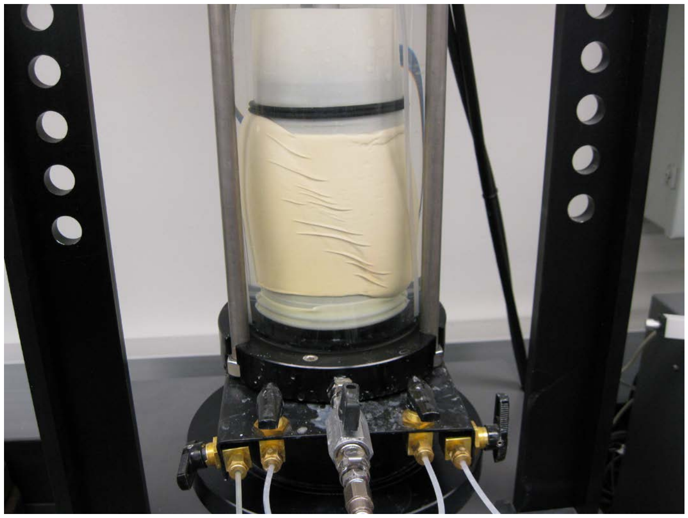

Figure 5: Photograph of clay specimen in triaxial device failing in compression.